2.2. ENVIRONMENTAL FATE

2.2.1. Fate in Terrestrial Environments

The dominant fate of TCE released to surface soils is volatilization. Because of its moderate water solubility, TCE introduced into soil (e.g., landfills) also has the potential to migrate through the soil into groundwater; this is confirmed by the relatively frequent detection of TCE in groundwater. Biodegradation in soil and groundwater may occur at a relatively slow rate (half-lives on the order of months to years) (Howard et al., 1991).

2.2.2. Fate in the Atmosphere

In the atmosphere, TCE is expected to be present primarily in the vapor phase, rather than sorbed to particulate, because of its high vapor pressure. Some removal by scavenging during wet precipitation is expected because of its moderate water solubility. The major degradation process affecting vapor-phase TCE is photo-oxidation by hydroxyl radicals. Photolysis in the atmosphere proceeds very slowly, if at all. TCE does not absorb ultraviolet light at wavelengths of <290 nm and thus, will not directly photolyze. Based on measured rate data for the vapor phase photo-oxidation reaction with hydroxyl radicals, the estimated half-life of TCE in the atmosphere is on the order of 1–11 days with production of phosgene, dichloroacetyl chloride (DCAC), and formyl chloride. Under smog conditions, degradation is more rapid (half-life on the order of hours) (HSDB, 2002; Howard et al., 1991).

2.2.3. Fate in Aquatic Environments

The dominant fate of TCE released to surface waters is volatilization (predicted half-life of minutes to hours). Bioconcentration, biodegradation, and sorption to sediments and suspended solids are not thought to be significant (HSDB, 2002). TCE is not hydrolyzed under normal environmental conditions. However, slow photo-oxidation in water (half-life of 10.7 months) has been reported (HSDB, 2002; Howard et al., 1991).

2.3. EXPOSURE CONCENTRATIONS

TCE levels in the various environmental media result from the releases and fate processes discussed in Sections 2.1 and 2.2. No statistically based national sampling programs have been conducted that would allow estimates of true national means for any environmental medium. A substantial amount of air and groundwater data, however, has been collected as well as some data in other media, as described below.

2.3.1. Outdoor Air—Measured Levels

TCE has been detected in the air throughout the United States. According to ATSDR (1997c), atmospheric levels are highest in areas concentrated with industry and population, and

lower in remote and rural regions. Table 2-5 shows levels of TCE measured in the ambient air at a variety of locations in the United States.

Table 2-5. Concentrations of TCE in ambient air

Area	Yr	Concentration (µg/m^3)	
		Mean	Range
Rural			
Whiteface Mountain, New York[a]	1974	0.5	<0.3–1.9
Badger Pass, California[a]	1977	0.06	0.005–0.09
Reese River, Nevada[a]	1977	0.06	0.005–0.09
Jetmar, Kansas[a]	1978	0.07	0.04–0.11
All rural sites	1974–1978		0.005–1.9
Urban and suburban			
New Jersey[a]	1973–1979	9.1	ND–97
New York City, New York[a]	1974	3.8	0.6–5.9
Los Angeles, California[a]	1976	1.7	0.14–9.5
Lake Charles, Louisiana[a]	1976–1978	8.6	0.4–11.3
Phoenix, Arizone[a]	1979	2.6	0.06–16.7
Denver, Colorado[a]	1980	1.07	0.15–2.2
St. Louis, Missouri[a]	1980	0.6	0.1–1.3
Portland, Oregon[a]	1984	1.5	0.6–3.9
Philadelphia, Pennsylvania[a]	1983–1984	1.9	1.6–2.1
Southeast Chicago, Illinois[b]	1986–1990	1.0	
East St. Louis, Illinois[b]	1986–1990	2.1	
District of Columbia[c]	1990–1991	1.94	1–16.65
Urban Chicago, Illinois[d]	pre–1993	0.82–1.16	
Suburban Chicago, Illinois[d]	pre–1993	0.52	
300 cities in 42 states[e]	pre–1986	2.65	
Several Canadian Cities[f]	1990	0.28	
Several United States Cities[f]	1990	6.0	
Phoenix, Arizona[g]	1994–1996	0.29	0–1.53
Tucson, Arizona[g]	1994–1996	0.23	0–1.47
All urban/suburban sites	1973–1996		0–97

[a]IARC (1995a).
[b]Sweet (1992).
[c]Hendler (1992).
[d]Scheff (1993).
[e]Shah (1988).
[f]Bunce (1994).
[g]Zielinska-Psuja (1998).

ND = nondetect

More recent ambient air measurement data for TCE were obtained from EPA's Air Quality System database at the AirData Web site: http://www.epa.gov/air/data/index.html (2007b). These data were collected from a variety of sources including state and local environmental agencies. The data are not from a statistically based survey and cannot be assumed to provide nationally representative values. The most recent data (2006) come from 258 monitors located in 37 states. The means for these monitors range from 0.03 to 7.73 µg/m^3

and have an overall average of 0.23 μg/m^3. Table 2-6 summarizes the data for the years 1999–2006. The data suggest that levels have remained fairly constant since 1999 at about 0.3 μg/m^3. Table 2-7 shows the monitoring data organized by land setting (rural, suburban, or urban) and land use (agricultural, commercial, forest, industrial, mobile, and residential). Urban air levels are almost 4 times higher than rural areas. Among the land use categories, TCE levels are highest in commercial/industrial areas and lowest in forest areas.

Table 2-6. TCE ambient air monitoring data (μg/m^3)

Yr	Number of monitors	Number of states	Mean	Standard deviation	Median	Range
1999	162	20	0.30	0.53	0.16	0.01–4.38
2000	187	28	0.34	0.75	0.16	0.01–7.39
2001	204	31	0.25	0.92	0.13	0.01–12.90
2002	259	41	0.37	1.26	0.13	0.01–18.44
2003	248	41	0.35	0.64	0.16	0.02–6.92
2004	256	37	0.32	0.75	0.13	0.00–5.78
2005	313	38	0.43	1.05	0.14	0.00–6.64
2006	258	37	0.23	0.55	0.13	0.03–7.73

Source: EPA's Air Quality System database at the AirData Web site: http://www.epa.gov/air/data/index.html.

Table 2-7. Mean TCE air levels across monitors by land setting and use (1985–1998)

	Rural	Suburban	Urban	Agricultural	Commercial	Forest	Industrial	Mobile	Residential
Mean concentration (μg/m^3)	0.42	1.26	1.61	1.08	1.84	0.1	1.54	1.5	0.89
n	93	500	558	31	430	17	186	39	450

Source: EPA's Air Quality System database at the AirData Web site: http://www.epa.gov/air/data/index.html.

2.3.2. Outdoor Air—Modeled Levels

Under the National-Scale Air Toxics Assessment program, EPA has compiled emissions data and modeled air concentrations/exposures for the Criteria Pollutants and Hazardous Air Pollutants (U.S. EPA, 2007a). The results of the 1999 emissions inventory for TCE were discussed earlier and results presented in Figures 2-2 and 2-3. A computer simulation model known as the Assessment System for Population Exposure Nationwide (ASPEN) is used to estimate toxic air pollutant concentrations (http://www.epa.gov/ttnatw01/nata/aspen.html). This model is based on the EPA's Industrial Source Complex Long Term model which simulates the behavior of the pollutants after they are emitted into the atmosphere. ASPEN uses estimates of toxic air pollutant emissions and meteorological data from National Weather Service Stations to

estimate air toxics concentrations nationwide. The ASPEN model takes into account important determinants of pollutant concentrations, such as:

- rate of release;
- location of release;
- the height from which the pollutants are released;
- wind speeds and directions from the meteorological stations nearest to the release;
- breakdown of the pollutants in the atmosphere after being released (i.e., reactive decay);
- settling of pollutants out of the atmosphere (i.e., deposition); and
- transformation of one pollutant into another (i.e., secondary formation).

The model estimates toxic air pollutant concentrations for every census tract in the continental United States, the Commonwealth of Puerto Rico and the U.S. Virgin Islands. Census tracts are land areas defined by the U.S. Bureau of the Census and typically contain about 4,000 residents each. Census tracts are usually smaller than 2 square miles in size in cities but much larger in rural areas.

Figure 2-4 shows the results of the 1999 ambient air concentration modeling for TCE. The county median air levels range from 0 to 3.79 $\mu g/m^3$ and an overall median of 0.054 $\mu g/m^3$. They have a pattern similar to the emission densities shown in Figure 2-3. These NSATA modeled levels appear lower than the monitoring results presented above. For example, the 1999 air monitoring data (see Table 2-6) indicates a median outdoor air level of 0.16 $\mu g/m^3$ which is about 3 times as high as the modeled 1999 county median (0.054 $\mu g/m^3$). However, it should be understood that the results from these two efforts are not perfectly comparable. The modeled value is a median of county levels for the entire United States which includes many rural areas. The monitors cover many fewer areas (n = 162 for 1999) and most are in nonrural locations. A better analysis is provided by EPA (2007a) which presents a comparison of modeling results from NSATA to measured values at the same locations. For 1999, it was found that formaldehyde levels were underestimated at 79% of the sites (n = 92). Thus, while the NSATA modeling results are useful for understanding geographic distributions, they may frequently underestimate ambient levels.

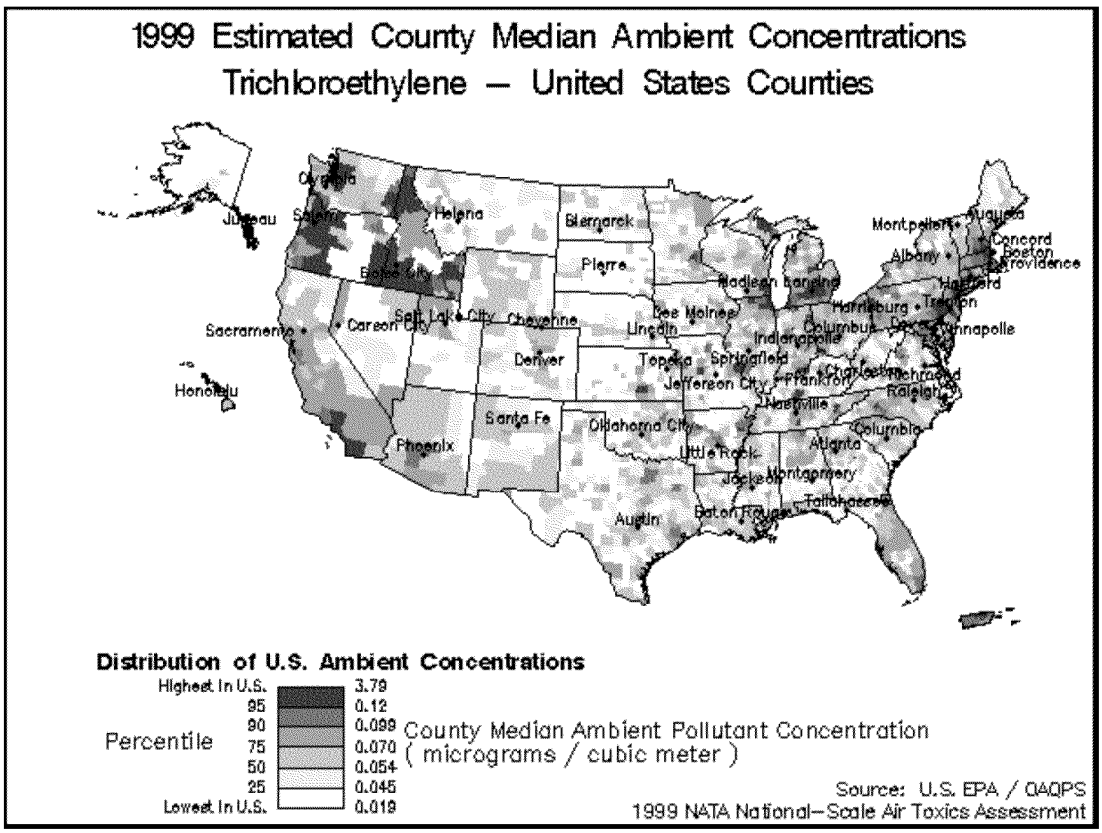

Figure 2-4. Modeled ambient air concentrations of TCE.

2.3.3. Indoor Air

TCE can be released to indoor air from use of consumer products that contain it (i.e., adhesives and tapes), vapor intrusion (migration of volatile chemicals from the subsurface into overlying buildings) and volatilization from the water supply. Where such sources are present, it is likely that indoor levels will be higher than outdoor levels. A number of studies have measured indoor levels of TCE:

- The 1987 EPA Total Exposure Assessment Methodology study (Wallace, 1987) showed that the ratio of indoor to outdoor TCE concentrations for residences in Greensboro, NC, was about 5:1.
- In two homes using well water with TCE levels averaging 22–128 µg/L, the TCE levels in bathroom air ranged from <500–40,000 µg/m^3 when the shower ran <30 minutes (Andelman, 1985).
- Shah and Singh (1988) report an average indoor level of 7.2 µg/m^3 based on over 2,000 measurements made in residences and workplaces during 1981–1984 from various locations across the United States.
- Hers et al. (2001) provides a summary of indoor air TCE measurements at locations in United States, Canada, and Europe with a range of <1–165 µg/m^3.

- Sapkota et al. (2005) measured TCE levels inside and outside of the Baltimore Harbor Tunnel toll booths during the summer of 2001. Mean TCE levels were 3.11 $\mu g/m^3$ indoors and 0.08 $\mu g/m^3$ outdoors based on measurements on 7 days. The authors speculated that indoor sources, possibly dry cleaning residues on uniforms, were the primary source of the indoor TCE.
- Sexton et al. (2005) measured TCE levels inside and outside residences in Minneapolis/St. Paul metropolitan area. Two day samples were collected over three seasons in 1999. Mean TCE levels were 0.5 $\mu g/m^3$ indoors ($n = 292$), 0.2 $\mu g/m^3$ outdoors ($n = 132$) and 1.0 $\mu g/m^3$ based on personal sampling ($n = 288$).
- Zhu et al. (2005) measured TCE levels inside and outside of residences in Ottawa, Canada. Seventy-five homes were randomly selected and measurements were made during the winter of 2002/2003. TCE was above detection limits in the indoor air of 33% of the residences and in the outdoor air of 19% of the residences. The mean levels were 0.06 $\mu g/m^3$ indoors and 0.08 $\mu g/m^3$ outdoors. Given the high frequency of nondetects, a more meaningful comparison can be made on basis of the 75th percentiles: 0.08 $\mu g/m^3$ indoors and 0.01 $\mu g/m^3$ outdoors.

TCE levels measured indoors have been directly linked to vapor intrusion at two sites in New York:

- TCE vapor intrusion has occurred in buildings/residences near a former Smith Corona manufacturing facility located in Cortlandville, New York. An extensive sampling program conducted in 2006-2007 has detected TCE in groundwater (up to 22 $\mu g/L$), subslab gas (up to 1,000 $\mu g/m^3$), and indoor air (up to 34 $\mu g/m^3$) (NYSDEC, 2007).
- Evidence of vapor intrusion of TCE has also been reported in buildings and residences in Endicott, New York. Sampling in 2003 showed total volatile organic compounds (VOCs) in soil gas exceeding 10,000 $\mu g/m^3$ in some areas. Indoor air sampling detected TCE levels ranging from 1 to 140 $\mu g/m^3$ (Meyers, 2003).

Little et al. (1992) developed attenuation coefficients relating contaminants in soil gas (assumed to be in chemical equilibrium with the groundwater) to possible indoor levels as a result of vapor intrusion. On this basis they estimated that TCE groundwater levels of 540 $\mu g/L$, (a high contamination level) could produce indoor air levels of 5–500 $\mu g/m^3$. Vapor intrusion can be an important contributor to indoor levels in situations where residences are located near soils or groundwater with high contamination levels. EPA (2002c) recommends considering vapor intrusion when volatiles are suspected to be present in groundwater or soil at a depth of <100 feet. Hers et al. (2001) concluded that the contribution of VOCs from subsurface sources relative to indoor sources is small for most chemicals and sites.